US009143479B2

(12) **United States Patent**
Arberg et al.

(10) **Patent No.:** **US 9,143,479 B2**
(45) **Date of Patent:** **Sep. 22, 2015**

(54) **DHCP PROXY IN A SUBSCRIBER ENVIRONMENT**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 413 days.

(21) Appl. No.: **13/557,128**

(22) Filed: **Jul. 24, 2012**

(65) **Prior Publication Data**

US 2013/0060891 A1 Mar. 7, 2013

Related U.S. Application Data

(63) Continuation of application No. 10/956,175, filed on Sep. 30, 2004, now Pat. No. 8,230,067.

(60) Provisional application No. 60/516,541, filed on Oct. 31, 2003.

(51) **Int. Cl.**
G06F 15/16 (2006.01)
H04L 29/12 (2006.01)

(52) **U.S. Cl.**
CPC ***H04L 61/2015*** (2013.01); ***H04L 29/1282*** (2013.01); ***H04L 61/6013*** (2013.01)

(58) **Field of Classification Search**
CPC H04L 61/2015; H04L 29/1282; H04L 61/6013; H04L 45/00; H04W 88/10
USPC 709/217
See application file for complete search history.

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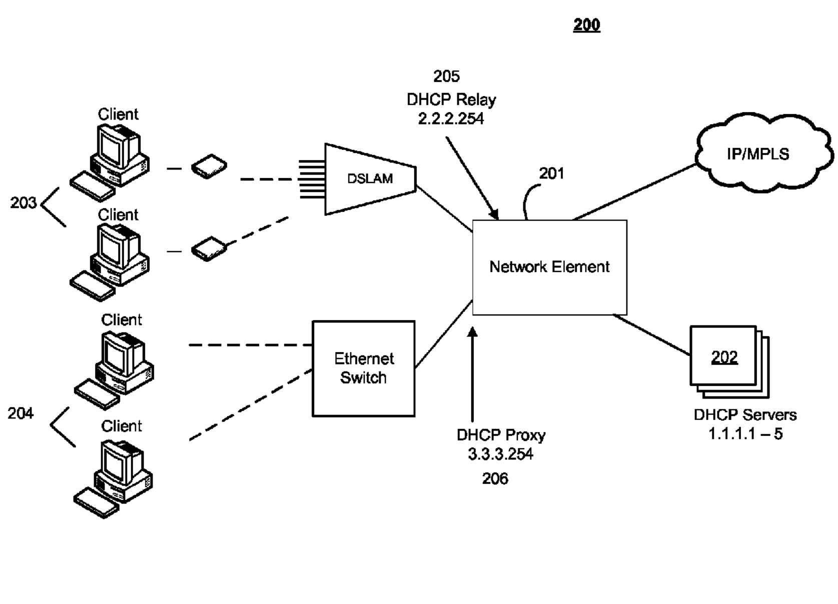
(57) **ABSTRACT**

Methods and apparatuses for a network element having DHCP proxy functionality are described. According to one embodiment, an exemplary method includes receiving, at a network element, a request for an IP address from a subscriber, in response to the request, on behalf of the subscriber, communicating with one or more IP address providers over a network to process the request, and responding to the subscriber with respect to the request as if the network element is an IP address provider, on behalf of the one or more IP address providers.

16 Claims, 13 Drawing Sheets



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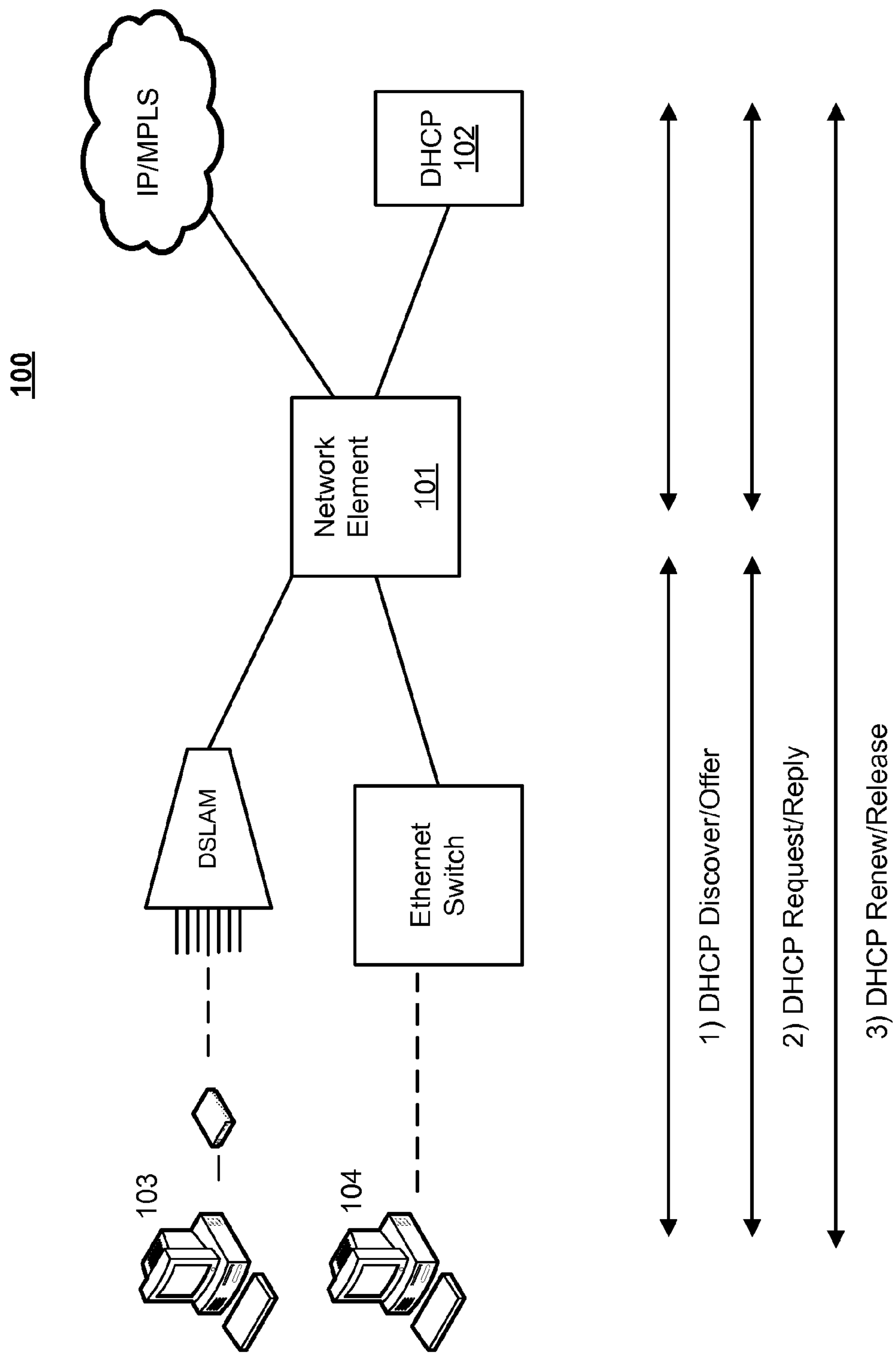

FIG. 1
(PRIOR ART)

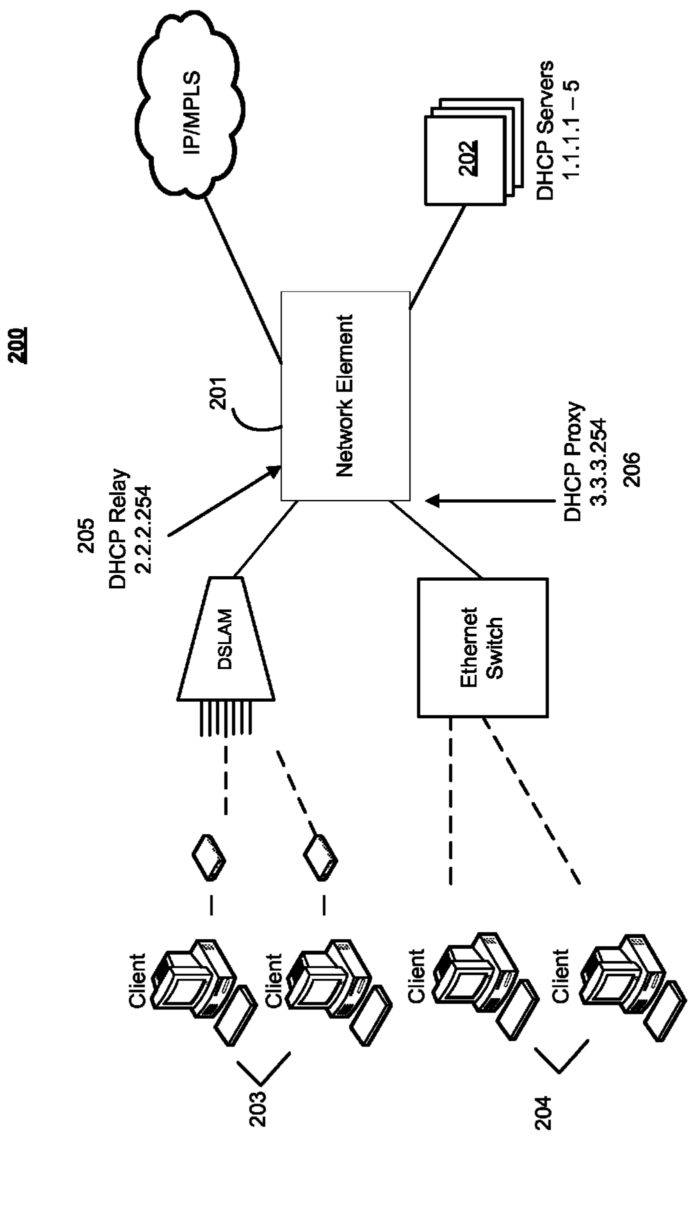
200
IP/MPLS
202
DHCP Servers
1.1.1.1 – 5
201
Network Element
205
DHCP Relay
2.2.2.254
DHCP Proxy
3.3.3.254
206
DSLAM
Ethernet Switch
Client
Client
Client
Client
203
204

FIG. 2

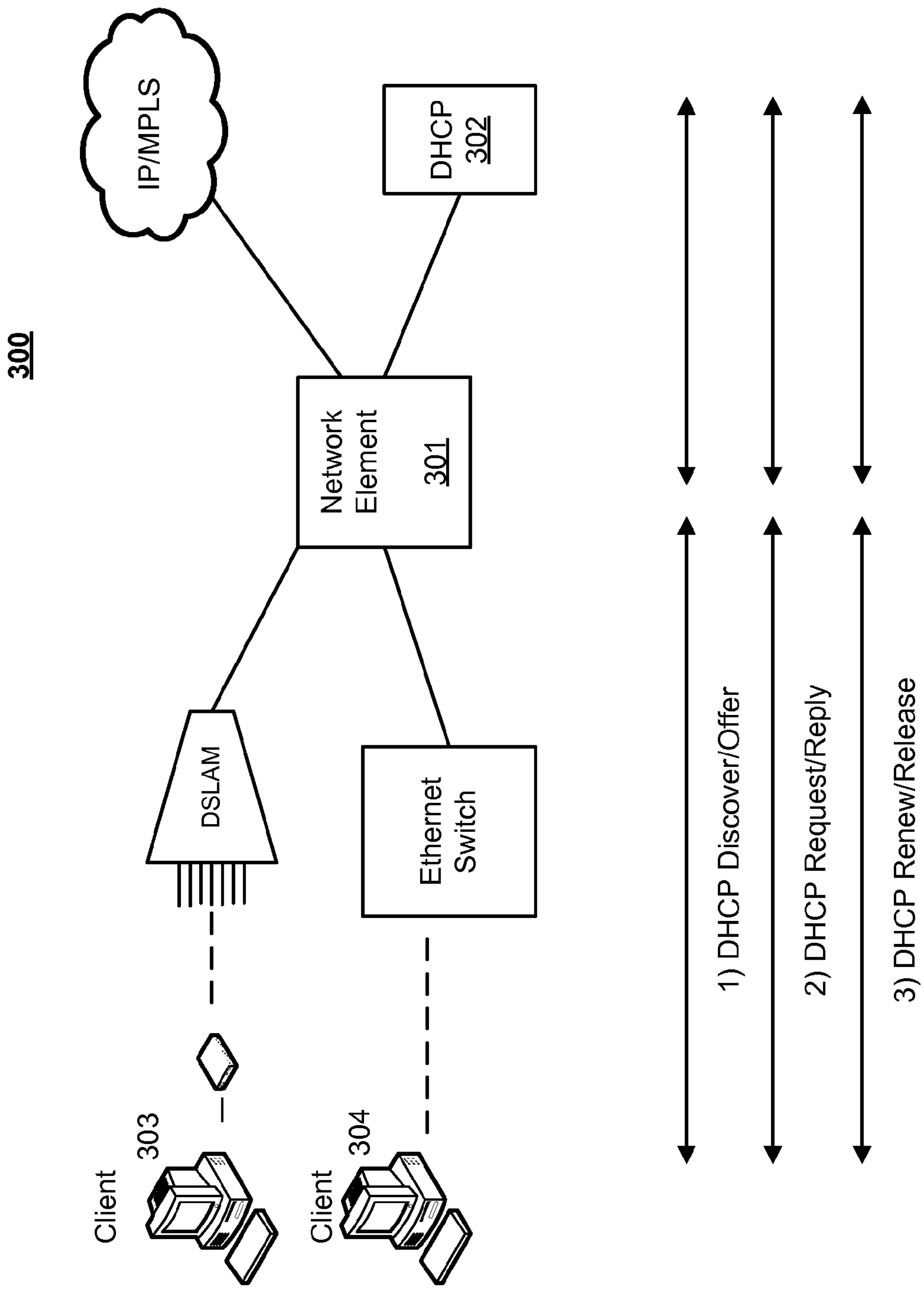
300
IP/MPLS
DHCP
302
Network Element
301
DSLAM
Ethernet Switch
Client
303
Client
304
1) DHCP Discover/Offer
2) DHCP Request/Reply
3) DHCP Renew/Release

FIG. 3

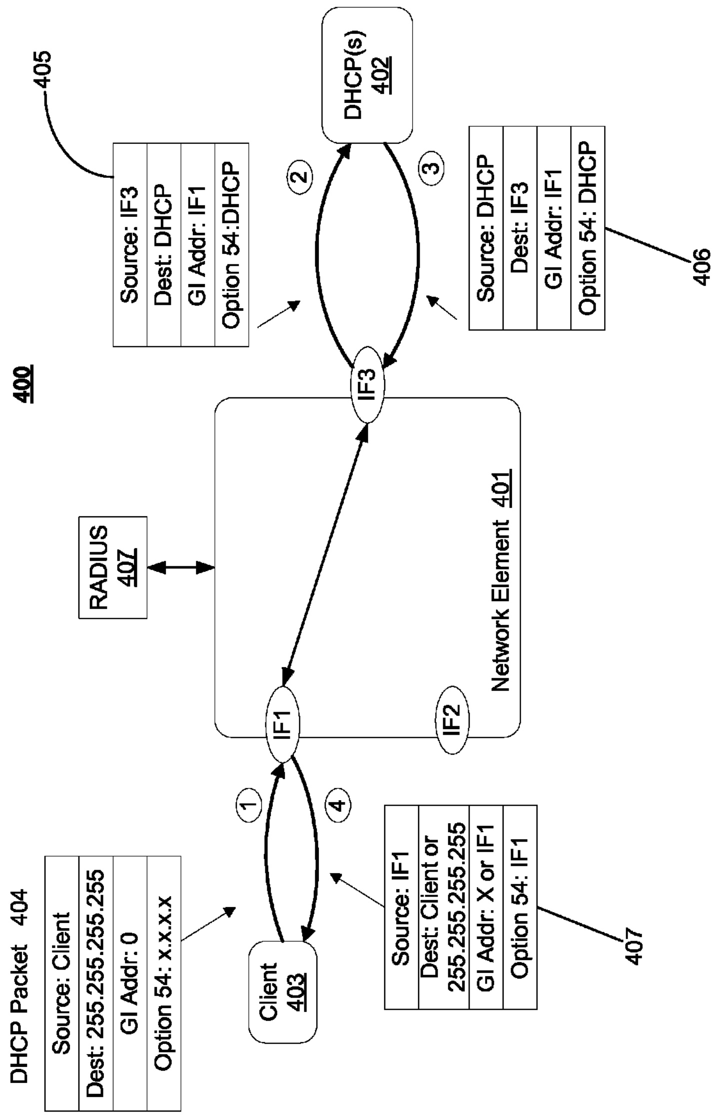
400
405
DHCP(s)
402
Source: IF3
Dest: DHCP
GI Addr: IF1
Option 54:DHCP
Source: DHCP
Dest: IF3
GI Addr: IF1
Option 54: DHCP
406
RADIUS
407
IF3
IF1
IF2
Network Element 401
DHCP Packet 404
Source: Client
Dest: 255.255.255.255
GI Addr: 0
Option 54: x.x.x.x
Client
403
Source: IF1
Dest: Client or 255.255.255.255
GI Addr: X or IF1
Option 54: IF1
407
1
2
3
4

FIG. 4A

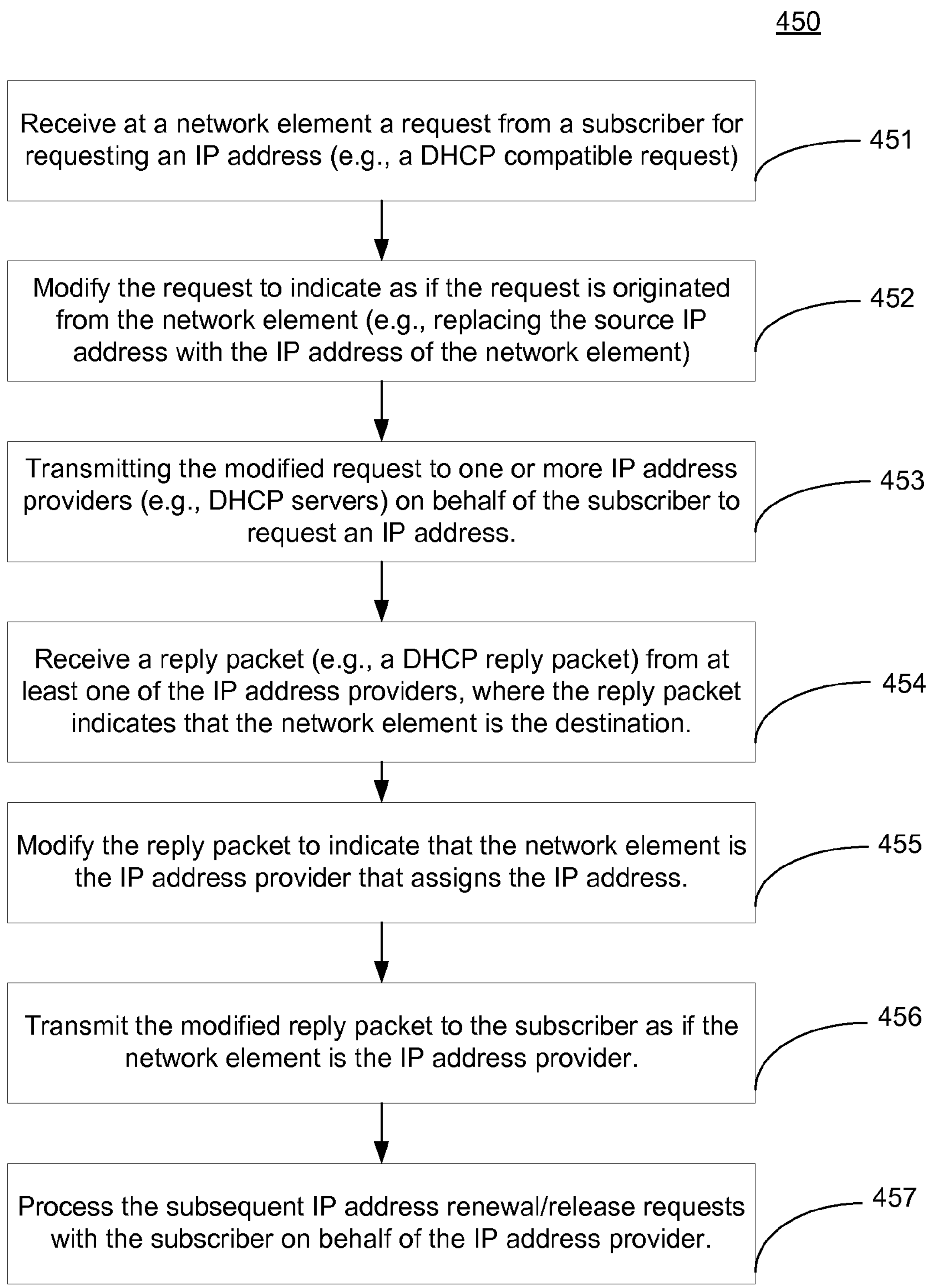
450
Receive at a network element a request from a subscriber for requesting an IP address (e.g., a DHCP compatible request)
451
Modify the request to indicate as if the request is originated from the network element (e.g., replacing the source IP address with the IP address of the network element)
452
Transmitting the modified request to one or more IP address providers (e.g., DHCP servers) on behalf of the subscriber to request an IP address.
453
Receive a reply packet (e.g., a DHCP reply packet) from at least one of the IP address providers, where the reply packet indicates that the network element is the destination.
454
Modify the reply packet to indicate that the network element is the IP address provider that assigns the IP address.
455
Transmit the modified reply packet to the subscriber as if the network element is the IP address provider.
456
Process the subsequent IP address renewal/release requests with the subscriber on behalf of the IP address provider.
457

FIG. 4B

500

Client ID	IP Address	MAC	Lease Time	Circuit Info	DHCP ID	GI Address
...	...	...	...	...	...	...

FIG. 5

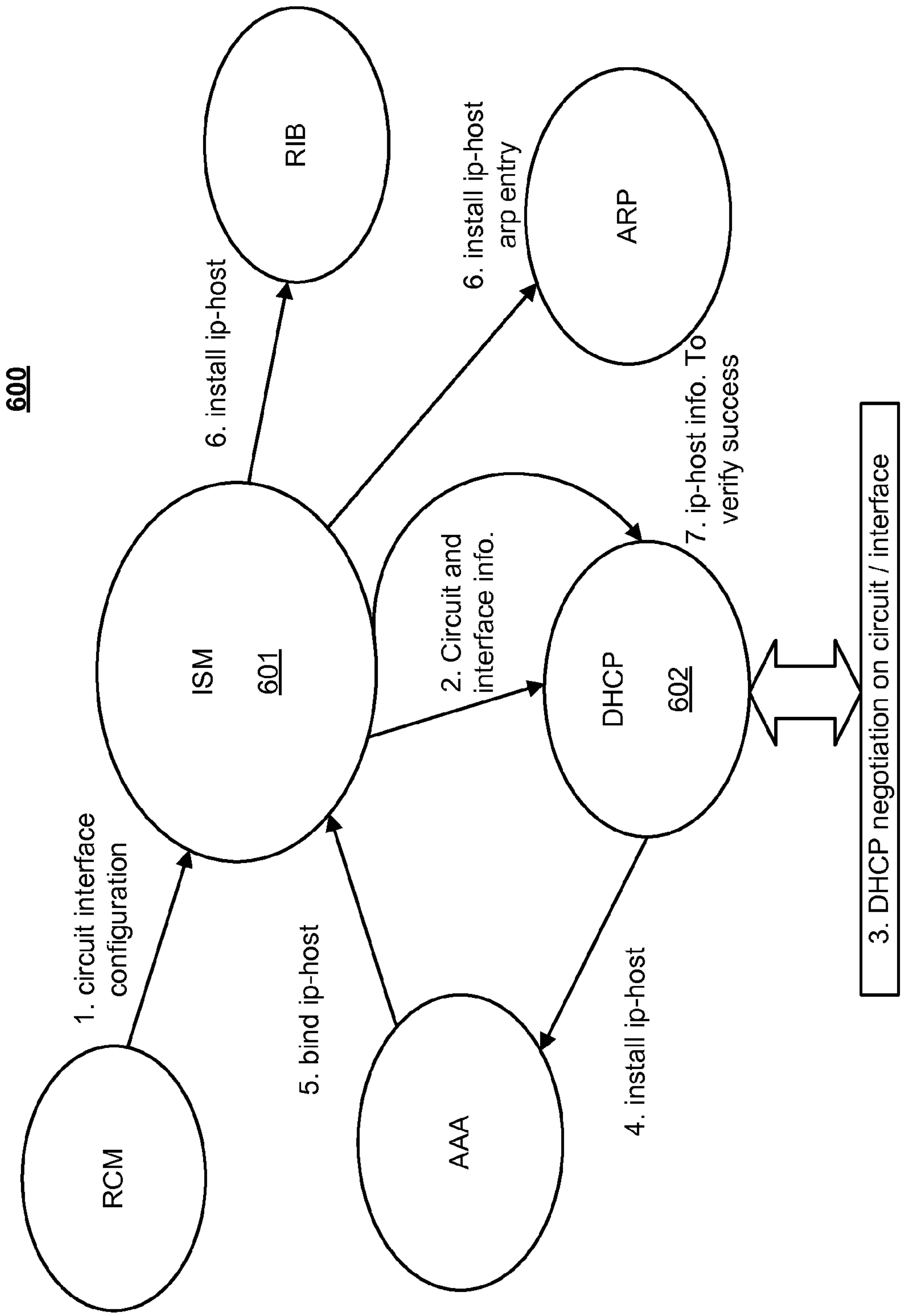
600
RIB
6. install ip-host
6. install ip-host
arp entry
ARP
ISM
601
2. Circuit and
interface info.
7. ip-host info. To
verify success
DHCP
602
3. DHCP negotiation on circuit / interface
1. circuit interface
configuration
5. bind ip-host
4. install ip-host
RCM
AAA

FIG. 6

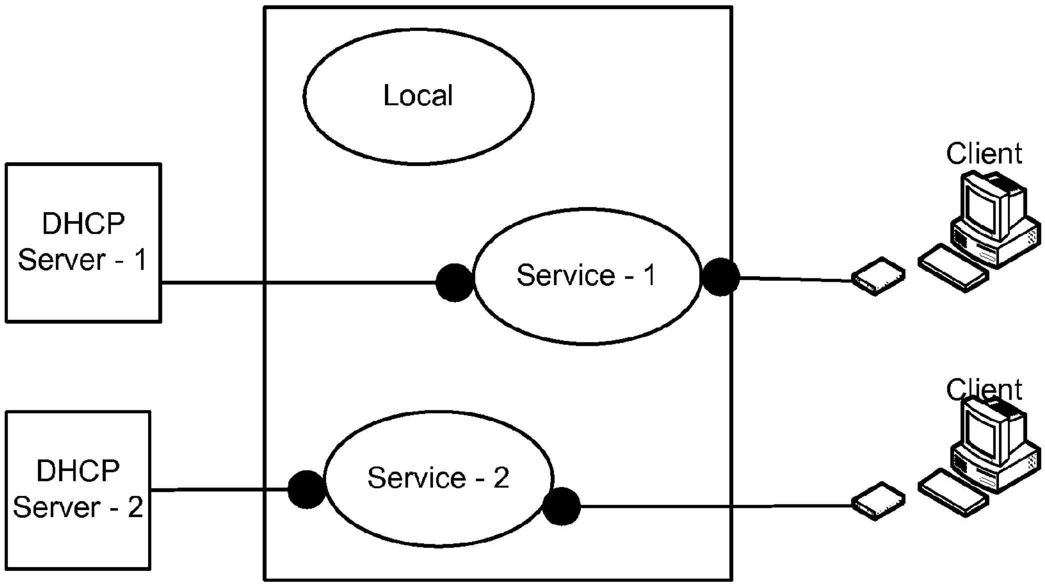
Local
DHCP Server - 1
Service - 1
Client
DHCP Server - 2
Service - 2
Client

FIG. 7A

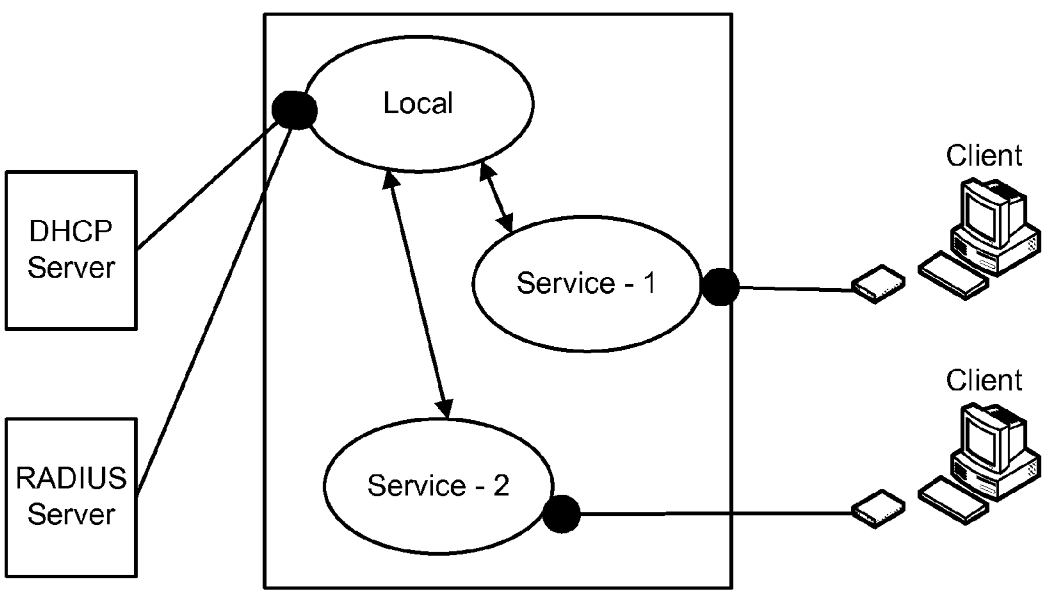
Local
DHCP Server
Service - 1
Client
RADIUS Server
Service - 2
Client

FIG. 7B

```
context service-1
dhcp relay server 192.168.1.100
dhcp relay option
interface subscribers multibind
     ip-address 10.10.1.1/24
     dhcp proxy
interface management
     ip-address 192.168.1.1/24
subscriber name sub1
     password test
     dhcp max-addrs 1
subscriber name sub2
     password test
     dhcp max-addrs 1
context service-2
. . .

port atm 2/1
     no shutdown
     atm pvc 1:32 profile vbr-nrt encapsulation
bridge1483
     bind subscriber subl@service-1
atm pvc 1:33 profile vbr-nrt encapsulation bridge1483
     bind subscriber sub2aservice-1
. . .
```

FIG. 8A

```
context local
  interface dhcp
    ip-address 192.168.1.1/24
!
ip route 10.1.1.1/32 context service-1
ip route 10.2.1.1/32 context service-2
!
context service-1
  dhcp relay server 192.168.1.100
  dhcp relay option
  interface subscribers multibind
    ip-address 10.10.1.1/24
    dhcp proxy
  interface management loopback
    ip-address 10.1.1.1/32
    ip source-address dhcp
  subscriber name subl
    password test
    dhcp max-addrs 1
  subscriber name sub2
    password test
    dhcp max -addrs 1
. . .
  ip route 192.168.1.0/24 context local
context service-2
  dhcp relay server 192.168.1.100
dhcp relay option
interface subscribers multibind
    ip-address 10.10.2.1/24
    dhcp proxy
interface management loopback
    ip-address 10.2.1.1/32
    ip source -address dhcp
  subscriber name subl
    password test
    dhcp max-addrs 1
  subscriber name sub2
    password test
    dhcp max-addrs 1
. . .
ip route 192.168.1.0/24 context local
port atm 2/1
  no shutdown
  atm pvc 1:32 profile vbr-nrt encapsulation bridge1483
bind subscriber subl@service-1
atm pvc 1:33 profile vbr-nrt encapsulation bridge1483
bind subscriber sub2Oservice-1
...
port atm 2/2
  no shutdown
  atm pvc 1:32 profile vbr-nrt encapsulation bridge1483
bind subscriber subl@service-2
atm pvc 1:33 profile vbr-nrt encapsulation bridge1483
  bind subscriber sub2Oservice-2
...
```

FIG. 8B

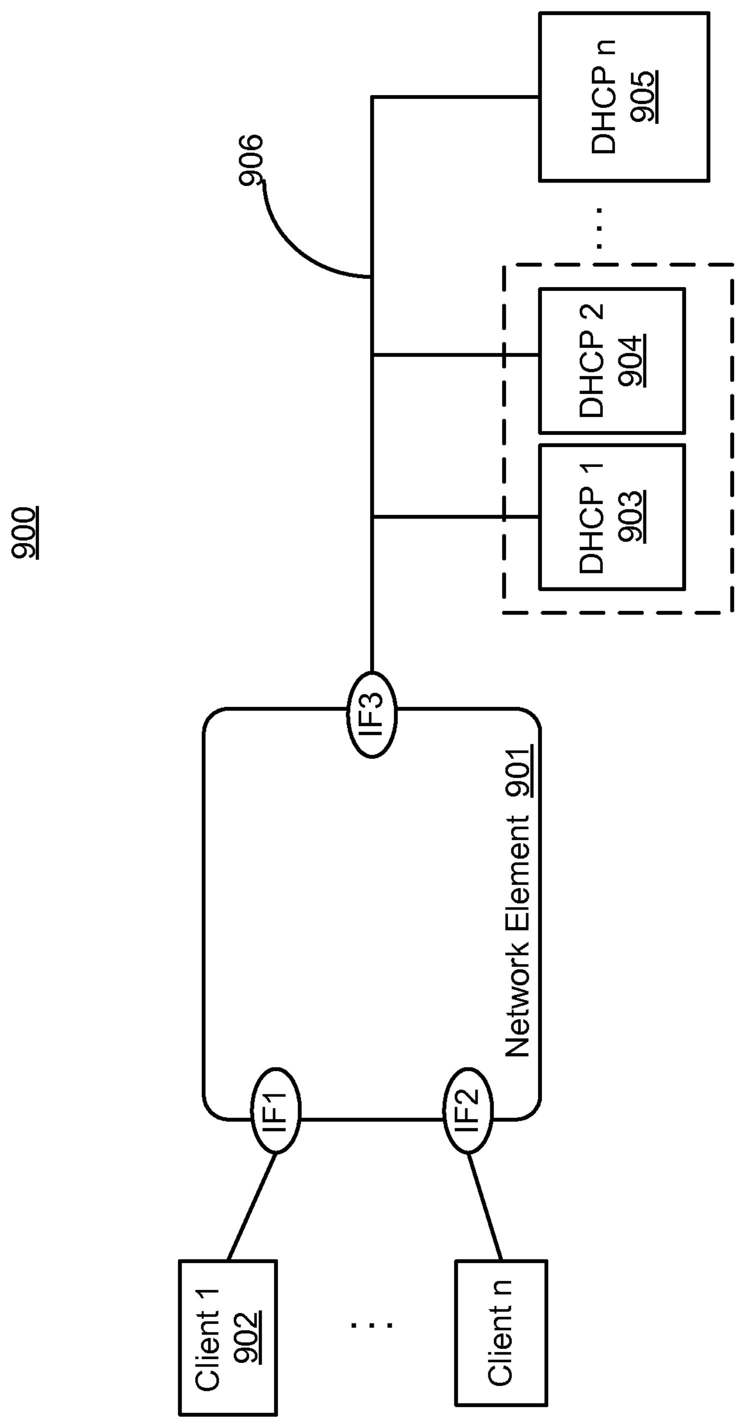
900
906
DHCP n
905
DHCP 2
904
DHCP 1
903
IF3
Network Element 901
IF1
IF2
Client 1
902
Client n

FIG. 9

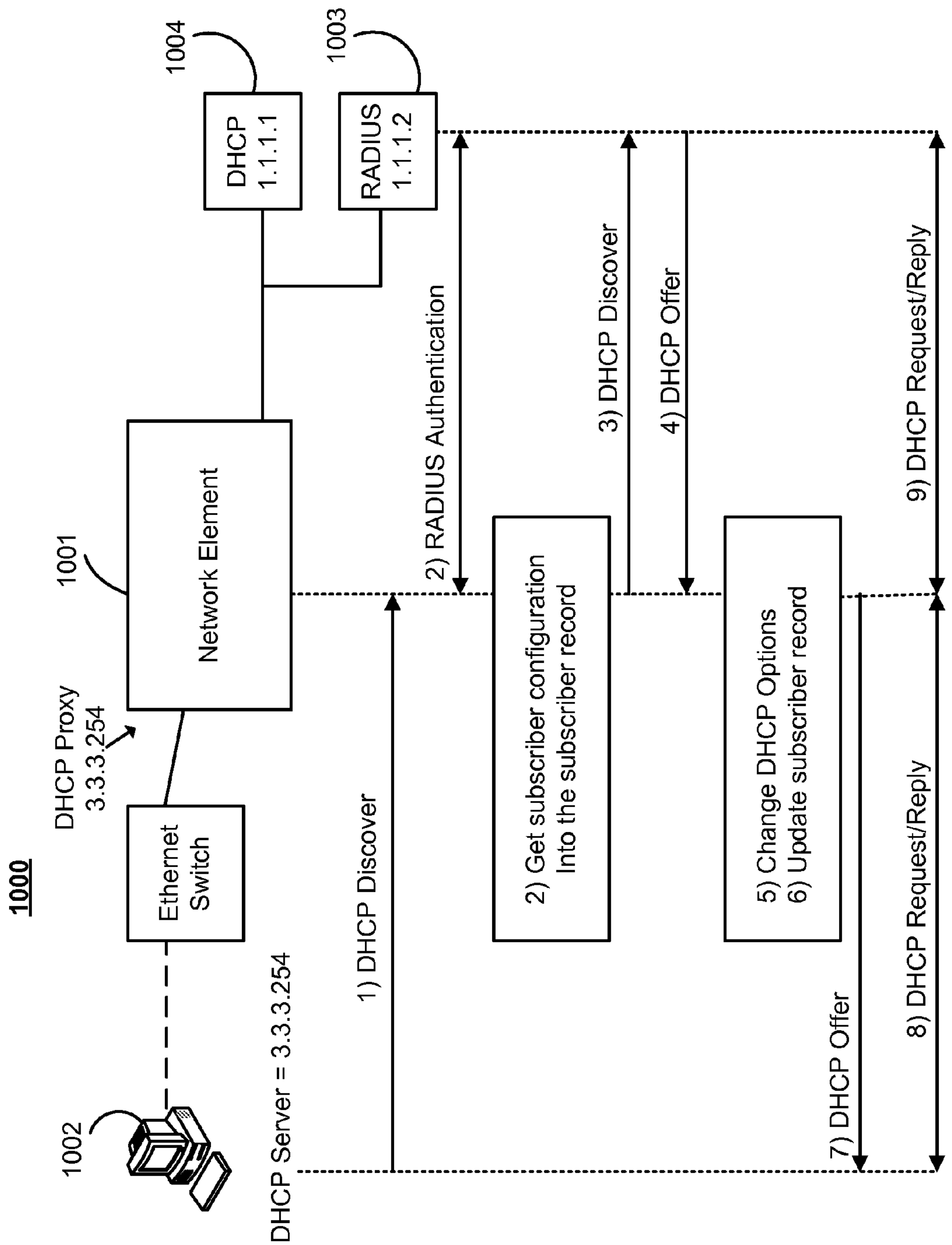
1000
1004
DHCP
1.1.1.1
1003
RADIUS
1.1.1.2
1001
Network Element
DHCP Proxy
3.3.3.254
Ethernet
Switch
1002
DHCP Server = 3.3.3.254
1) DHCP Discover
2) RADIUS Authentication
2) Get subscriber configuration
Into the subscriber record
3) DHCP Discover
4) DHCP Offer
5) Change DHCP Options
6) Update subscriber record
7) DHCP Offer
8) DHCP Request/Reply
9) DHCP Request/Reply

FIG. 10

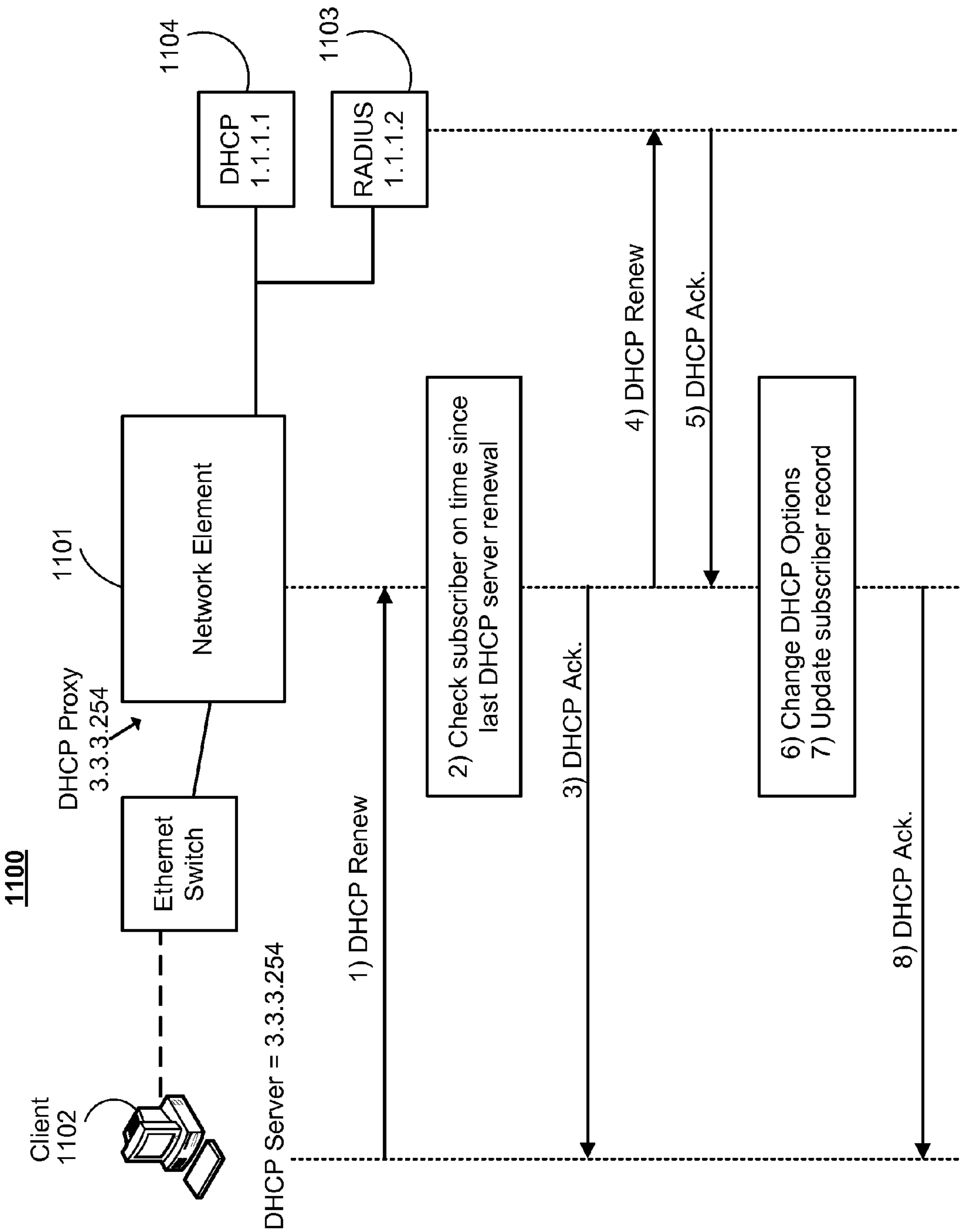
1100
Client
1102
DHCP Server = 3.3.3.254
Ethernet Switch
DHCP Proxy
3.3.3.254
1101
Network Element
1104
DHCP
1.1.1.1
1103
RADIUS
1.1.1.2
1) DHCP Renew
2) Check subscriber on time since last DHCP server renewal
3) DHCP Ack.
4) DHCP Renew
5) DHCP Ack.
6) Change DHCP Options
7) Update subscriber record
8) DHCP Ack.

FIG. 11

DHCP PROXY IN A SUBSCRIBER ENVIRONMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 10/956,175, filed Sep. 30, 2004, which claims the benefit of U.S. Provisional Application No. 60/516,541, filed Oct. 31, 2003, which are both hereby incorporated by reference.

FIELD OF THE INVENTION

The present invention relates generally to communications. More particularly, this invention relates to a network element acting as a DHCP proxy.

BACKGROUND OF THE INVENTION

In the field of communications, the need for high-speed transmission of data, including video and audio, has continued to increase. Moreover, there has been an increase in the selection of services by which users can connect to a network, such as the Internet. Specifically, Internet Service Providers (ISPs) may allow for connectivity to the Internet through lower-speed connections at different rates, such as 56 kilobits/second, by employing a Plain Old Telephone Service (POTS) line. Other choices for connection, which are at higher speeds, into a network can include Integrated Services Digital Network (ISDN), Digital Subscriber Line (DSL) service, and cable modem service over a Radio Frequency (RF) cable line. Further, other types of content providers may enable a subscriber to receive different types of media, such as a video stream, audio stream, etc.

In a typical DSL network, a network element supports a wide variety of features to facilitate the management, allocation and distribution of IP addresses. Normally, the subscriber profile can be configured locally on the network element or can be retrieved from a RADIUS (remote access dial in user server) remote server (e.g.). A subscriber profile determines how an IP address (and optionally the associated route for the subscriber LAN) would be provided to a certain subscriber.

Typically, a DHCP (dynamic host configuration protocol) server is responsible for allocating and assigning one or more IP addresses to one or more clients. FIG. **1** is a block diagram illustrating a typical network configuration. In this configuration, a network element **101** serves a relay agent with respect to DHCP server **102** for one or more clients **103** and **104**. Typically, when client **103** desires to enter the network, client **103** sends a DHCP discovery broadcasts to network element **101**. Network element **101** forwards the request to DHCP server **102**. DHCP server **102** then returns an offer back to network element **101** which in turn forwards it back to client **103**. When DHCP **102** assigns an IP address to client **103**, DHCP **102** replies with a DHCP packet (e.g., a DHCPack) to client **103**. When network element **101** forwards this DHCP reply to client **103**, network element **101** installs an IP-host route and an ARP entry for the IP address assigned to client **103**. Client **103** now has a valid IP address and it knows the IP address of the DHCP **102**. Further communications between client **103** and DHCP **102**, such as DHCP lease renewal and release, will take place between client **103** and DHCP **102** directly without substantially invoking network element **101**.

However, since network element **101** may communicate and service thousands of clients. Each client may need to directly communicate with DHCP **102** for, for example, IP

address renewal or release. DHCP **102** may also service other network elements, which may provide services for thousands of other clients. As a result, DHCP **102** may experience heavy traffic from all clients via all network elements.

An IP address may be explicitly released by the client or implicitly released through the expiration of the lease time. In either case, sub-released IP addresses should be available for allocation and assignment.

When client **103** releases the IP address back to DHCP **102**, network element **101** has no knowledge whether the IP address has been released until network element **101** sees DHCP **102** assigns that IP address to another of network element's **101** clients. Instead, network element **101** keeps listening to the traffic associated with the IP address until network element **101** sees DHCP **102** assigns that IP address to another of network element's **101** clients. Thus, network element **101** may consider that the IP address is still in use even though client **103** has released the IP address (directly back to DHCP **102**). In addition to the resources of network element **103** wasted on such listening, this approach may result in an under utilization of IP addresses where DHCP **102** is serially resulting the network elements. Specifically, where DHCP **102** is servicing multiple network elements, DHCP **102** cannot allocate and assign a released IP address to a first network element while a second network element is listening for that IP address (that is, since the second network element listening for the released IP address will not see the reallocation and assignment of that IP address to a client of the first network element. The second network element will not know to stop listening and problems arise if two network elements are listening for the same IP address). This restriction typically leads DHCP **102** to be configured to designate different blocks of IP address to different network elements; if a given network element needs additional IP addresses, DHCP **102** cannot give it IP addresses designated to another network element even if they are not being used.

In addition, DHCP **102** typically maintains all lease time information for all clients. As a result, every client's DHCP renewal or release has to be processed by DHCP **102**, which significantly increases the overhead traffic of DHCP **102**. Furthermore, since network element **101** has no knowledge when the lease time expires, network element **101** has to keep listening for the IP address associated with the expired lease. Since allowing a lease to expire has the same effect as a client explicitly releasing an IP address, listening to an IP address for which the lease has expired has the same disadvantages as those described above with regard to when a client explicitly releases an IP address.

SUMMARY OF THE INVENTION

Methods and apparatuses for a network element having DHCP proxy functionality are described. According to one embodiment, an exemplary method includes receiving, at a network element, a request for an IP address from a subscriber, in response to the request, on behalf of the subscriber, communicating with one or more IP address providers over a network to process the request, and responding to the subscriber with respect to the request as if the network element is an IP address provider, on behalf of the one or more IP address providers.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings in which like references indicate similar elements.

FIG. **1** is a diagram illustrating a typical network infrastructure.

FIG. **2** is a diagram illustrating an exemplary network infrastructure according to one embodiment of the invention.

FIG. **3** is a flow diagram illustrating an exemplary process for processing a request for an IP address according to one embodiment of the invention.

FIG. **4**A is a block diagram illustrating an exemplary process for processing a request for an IP address according to one embodiment of the invention.

FIG. **4**B is a flow diagram illustrating an exemplary process for processing a request for an IP address according to another embodiment of the invention.

FIG. **5** is a block diagram illustrating an exemplary data structure which may be used in one embodiment of the invention.

FIG. **6** is a block diagram illustrating an exemplary information flow within a network element according to one embodiment of the invention.

FIGS. **7**A and **7**B are block diagrams illustrating exemplary configurations of a network element according to one embodiment of the invention.

FIGS. **8**A and **8**B are diagrams illustrating exemplary codes for configuring a network element according to one embodiment of the invention.

FIG. **9** is a block diagram illustrating an exemplary network configuration having redundant DHCP servers according to one embodiment of the invention.

FIG. **10** is a flow diagram illustrating an exemplary process for DHCP discovery according to one embodiment of the invention.

FIG. **11** is a flow diagram illustrating an exemplary process for DHCP renewal according to one embodiment of the invention.

DETAILED DESCRIPTION

In the following description, numerous details are set forth to provide a more thorough explanation of the present invention. It will be apparent, however, to one skilled in the art, that the present invention may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form, rather than in detail, in order to avoid obscuring the present invention.

Some portions of the detailed descriptions which follow are presented in terms of algorithms and symbolic representations of operations on data bits within a computer memory. These algorithmic descriptions and representations are the means used by those skilled in the data processing arts to most effectively convey the substance of their work to others skilled in the art. An algorithm is here, and generally, conceived to be a self-consistent finite sequence of steps leading to a desired result. The steps are those requiring physical manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It has proven convenient at times, principally for reasons of common usage, to refer to these signals as bits, values, elements, symbols, characters, terms, numbers, or the like.

It should be borne in mind, however, that all of these and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities. Unless specifically stated otherwise as apparent from the following discussion, it is appreciated that throughout the description, discussions utilizing terms such as "processing" or "computing" or "calculating" or "determining" or "displaying" or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission or display devices.

The invention also relates to one or more different apparatuses for performing the operations herein. This apparatus may be specially constructed for the required purposes (e.g., software, hardware, and/or firmware, etc.), or it may comprise a general purpose computer selectively activated or reconfigured by a computer program stored in the computer. The instructions of such software, firmware, and computer programs may be stored in a machine readable medium, such as, but is not limited to, any type of disk including floppy disks, optical disks, CD-ROMs, and magnetic-optical disks, read-only memories (ROMs), random access memories (RAMs), erasable programmable ROMs (EPROMs), electrically erasable programmable ROMs (EEPROMs), magnetic or optical cards, electrical, optical, acoustical or other forms of prorogated signals (e.g., carrier waves, infrared signals, etc.) or any type of media suitable for storing electronic instructions.

The algorithms and displays presented herein are not inherently related to any particular computer or other apparatus. Various general purpose systems may be used with programs in accordance with the teachings herein, or it may prove convenient to construct more specialized apparatus to perform the required method steps. The required structure for a variety of these systems will appear from the description below. In addition, the present invention is not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings of the invention as described herein.

Methods and apparatuses for a network element having DHCP proxy functionality are described. In certain embodiments of the invention, a network element that connects clients to a DHCP server acts as a proxy for that DHCP server. In addition, certain of these embodiments allow the network element to: 1) acts as a DHCP proxy for multiple DHCP servers configured to provide redundancy; and/or **2**) to facilitate the handling of lease renewals.

FIG. **2** is a block diagram illustrating an exemplary network configuration according to one embodiment of the invention. Referring to FIG. **2**, according to one embodiment, exemplary network configuration **200** includes a network element **201** to communicate with one or more clients **203** and **204**. Network element **201** includes a DHCP relay interface **205** for relaying DHCP requests to one of a set if one or more DHCP servers **202**, similar to the one shown in FIG. **1**. In addition, network element **201** includes a DHCP proxy interface for serving as a DHCP proxy on behalf of DHCP servers **202**. In this embodiment, clients **203** communicate via DHCP relay interface of network element **201** with one of DHCP servers **202**. After acquiring IP addresses from DHCP servers **202**, clients **203** directly communicate with one of the DHCP servers **202** without involving DHCP relay interface **205** of network element **201**. That is, when clients **203** communicate with DHCP **202**, clients **203** will specify DHCP **202**'s IP address as its destination IP address (e.g., 1.1.1.1-1.1.1.5) in a communication packet, instead of DHCP relay interface's IP address (e.g., 2.2.2.254).

However, clients **204** communicate with proxy interface **206** of network element **201**, which in turn communicates with DHCP servers **202**. In this case, proxy interface **206** serves as a proxy of DHCP **202**. That is, proxy interface **206** acts as a DHCP server on behalf of DHCP servers **202**. When clients **204** communicate with a DHCP server, clients **204** will specify DHCP proxy interface's IP address (e.g., 3.3.3.254) as its destination IP address instead of DHCP **202**'s IP address (e.g., 1.1.1.1-1.1.1.5), because clients **204** consider that proxy interface **206** is the DHCP server they are communicating with.

Since network element **201** serves as a proxy on behalf of one or more DHCP servers **202** having IP addresses from, for example, 1.1.1.1 to 1.1.1.5, network element **201** can maintain multiple DHCP servers and some of which may be used as redundant DHCP servers for backup purposes, which will be described in details further below. In addition, since network element **201** knows which subscriber is assigned with an IP address from which DHCP server, network element **201** may maintain lease time for each subscriber, which will be described in details further below. As a result, when a client releases its IP address back to network element **201** (since the client thinks network element **201** is the DHCP server), network element **201** knows that IP address has been released and network element **201** does not have to keep listening to the traffic of the released IP address. In addition, where DHCP servers **202** service multiple network elements, a reloaded IP address may be reassigned to another subscriber of another network element. Note that DHCP relay interface **205** of network element **201** is not required for network element **201** to operate, particularly to include a DHCP proxy interface.

FIG. **3** is a diagram illustrating an exemplary network configuration according to one embodiment of the invention. In this embodiment, referring to FIG. **3**, exemplary network configuration **300** includes network element **301** having an interface to serve as a DHCP proxy on behalf of DHCP server **302** to provide DHCP services to one or more clients **303** and **304**. The interface having DHCP proxy functionality may be implemented as proxy interface **206** of FIG. **2**. According to one embodiment, when client **303** requests for a DHCP service, client **303** sends a DHCP discovery broadcasts to network element **301**. Network element **301** forwards the message to DHCP server **302** and the DHCP offer and request processes take place via network element **301**. When DHCP **302** assigns an IP address to client **303**, DHCP **302** replies with a DHCP packet, such as a DHCPack, which is received by network element **301**. Prior to network element **301** forwarding this DHCP reply packet to client **303**, network element **301** changes DHCP IP address in the packet, from DHCP **302**'s IP address to network element **301**'s IP address. In addition, network element **301** installs an IP-host route and an ARP entry for the IP address assigned to client **303**. Thereafter, client **303** has a valid IP address and client **303** knows the IP address of network element **301**, and considers network element **301** as a DHCP server. Subsequently, client **303** may further communicate with network element **301** as a DHCP server for, for example, the DHCP renewal or release.

Note that both the DHCP relay and proxy functionality may work with either a "bind interface" or a "bind subscriber" statement. The "bind interface" can be considered as a non-subscriber mode where AAA (authorization, authentication, and accounting) is not involved, and a "bind subscriber" can be considered as a subscriber mode where AAA is involved for accounting purpose.

FIG. **4**A is a block diagram illustrating an exemplary DHCP process according to one embodiment of the invention. Exemplary process **400** may be implemented in exemplary network configuration **300** of FIG. **3**. In one embodiment, network element **401** includes a DHCP proxy functionality to enable at least one interface, such as interface IF**1**, to serve as a DHCP proxy to client **403** on behalf of DHCP **402**. Client **403** considers interface IF**1** of network element **401** is the DHCP server for the client.

Referring to FIG. **4**A, when client **403** broadcasts a DHCP broadcast message, client **403** sends a broadcast packet **404** in a network. In one embodiment, packet **404** includes, but not limited to, a source IP address (e.g., the IP address of client **403** or 0.0.0.0) and destination IP address is 255.255.255.255 indicating this message is a broadcast message. Since this is a DHCP broadcast message, the GI address and option **54** fields are irrelevant. When network element **401** receives packet **404**, network element **401** may perform optional AAA processes with RADIUS **407**, particularly when the DHCP proxy functionality is configured as per subscriber basis. Then network element **401** forwards the packet to an outlet interface IF**3** which will forward the packet to the DHCP **402**. Before transmitting the packet to IF**3**, network element **401** modifies the packet (e.g., packet **405**). In one embodiment, network element **401** replaces the source IP address of the packet with the outlet interface IF**3**'s IP address and the destination IP address with the DHCP **402**'s IP address. In addition, network element **401** may set the GI address field as the inlet interface IF**1**'s IP address and the option **54** field as DHCP **402**'s IP address. Furthermore, (e.g., if client **403** does not specify option **82** field of the packet **404**, always, etc.) network element may fill in the circuit information in the option **82** field, such as, for example, the slot number, the port number, and/or the PVC ID, etc.

When DHCP **402** receives forwarded broadcast message **405**, DHCP **402** returns an offer message **406** back to IF**1** via IF**3** of network element **401**. In one embodiment, DHCP **402** specifies, in return packet **406**, its IP address as the source IP address, IF**1**'s IP address as a destination IP address. In addition, DHCP **402** specifies IF**1**'s IP address as a GI address in the packet and its IP address in the option **54** field. When network element **401** receives packet **406**, it modifies the packet (e.g., packet **407**). In one embodiment, the modification includes replacing the source IP address with IF**1**'s IP address which indicates that IF**1** of network element **401** is the DHCP with respect to client **403**. In addition, network element **401** may change the GI address to the IF**1**'s IP address and changes the option **54** field as the IF**1**'s IP address. Furthermore, if network element **401** modified the option **82** field when it received the DHCP broadcast message, network element **401** may strip off the option **82** field when it forwards the offer packet **407** back to client **403**.

Thereafter, during the subsequent communications, such as, DHCP request or DHCP release, client **403** may use the IP address of interface IF**1** of network element **401** as a destination IP address and IF**1**'s IP address as the DHCP server address in the option **54** field, because client **403** was "told" that interface IF**1** of network element **401** is the DHCP server when it received the DHCP offer. FIG. **5** is a block diagram illustrating an exemplary data structure maintained by a network element according to one embodiment of the invention, in order to accomplish the processes described above.

Thus, since network element **401** serves as a DHCP proxy on behalf of DHCP **402**, according to one embodiment, multiple DHCP servers may be maintained without the knowledge of client **403**. At least one of the multiple DHCP servers may serve as a redundant DHCP server. In addition, according to another embodiment, network element **401** may maintain lease time information for client **403** since network element operates as a DHCP server with respect to client **403**. As a result, the subsequent DHCP renewal or release may be partially or fully handled by network element **401** without invoking DHCP **402** which greatly reduces traffic to DHCP **402**.

FIG. **4**B is a flow diagram illustrating an exemplary process for process a request for an IP address in accordance with one embodiment of the invention. Exemplary process **450** may be performed by a processing logic that may comprise hardware (circuitry, dedicated logic, etc.), software (such as is run on a dedicated machine), or a combination of both. For example, the exemplary process **450** may be performed by a network element, such as, network elements **201**, **301**, and **401**. In one embodiment, exemplary process **450** includes, but is not limited to, receiving, at a network element, a request for an IP address from a subscriber, in response to the request, on behalf of the subscriber, communicating with one or more IP address providers over a network to process the request, and responding to the subscriber with respect to the request as if the network element is an IP address provider, on behalf of the one or more IP address providers.

Referring to FIG. **4**B, at block **451**, a request for an IP address is received by a network element from a subscriber subscribing network services provided from one or more service providers. In one embodiment, the request is a DHCP compatible request, such as, for example, packet **404** of FIG. **4**A.

In response to the request, at block **452**, the network element may modify the request to indicate as if the request is originated from the network element. For example, the network element may replace the source IP address with the IP address of the network element. The network element may further modify the destination IP address of the packet using a destination IP address of an IP address provider (e.g., DHCP server). Other fields of the packet may also be modified. The modified packet may be similar to packet **405** of FIG. **4**A.

At block **453**, the modified packet is transmitted from the network element to the selected IP address provider on behalf of the subscriber. That is, the modified packet is transmitted from the network element to the selected IP address provider as if the network element is the source and the client of the IP address provider.

In response to the modified request received by the selected IP address provider, at block **454**, a reply packet is received by the network element from the IP address provider. The reply packet indicates that the network element is the destination of the reply packet, because the original modified packet indicates that the network element is the source of the request.

At block **455**, the network element may modify the reply packet to indicate that the network element is the source of the reply packet (e.g., the IP address provider that assigns the IP address). In one embodiment, the network element replaces the destination using the identity of the subscriber, which was obtained via the original IP address request. The network element may further specify in the source of the reply packet using an identity of the network element (e.g., IP address of the network element).

At block **456**, the modified reply packet is transmitted from the network element to the subscriber as if the network element is the IP address provider that assigns the IP address. Thereafter, at block **457**, the network element processes the subsequent IP address related services with the subscriber on behalf of the IP address provider. Other operations may also be performed.

According to one embodiment, a network element having functionality described above may be configured via at least one of the following commands:

Command	[no] dhcp relay server ip-addr
Command Mode	Context configuration
Default Behavior	no dhcp relay is configured

This command enables the DHCP relay and proxy functionality in a context. According to one embodiment, all DHCP requests received on interfaces in this context will be forwarded to the external DHCP sever with specified IP address.

Command	[no] dhcp relay option
Command Mode	Context configuration
Default Behavior	no dhcp relay option

This command will enable the sending of DHCP options in all DHCP packets being relayed from this context of the network element.

Command	[no] dhcp {relay | proxy} [size <max-num>]
Command Mode	Interface configuration
Default Behavior	no, relay/proxy is disabled on the interface

These commands will enable or disable either DHCP relay or proxy on a specific interface. It also sets the maximum number of DHCP IP address available on this interface via the size <max-num> option. The max-num can be configured between 1 and 65,535.

Command	Ip source-address {dhcp}
Command Mode	Interface configuration
Default Behavior	no DHCP source-address is configured

This command works with DHCP packets sourced from a network element. It is important that the IP address is controlled with which the network element is acting as a DHCP server in the proxy configuration. If "ip source-address" is not configured the interface ip-address from where the packet is transmitted is used as source address, but in applications where only one DHCP address is used in a network element, and intercontext routing is enabled, it becomes important that each context is uniquely identified by a single source-address.

Command	[no] dhcp max-addrs max-num
Command Mode	Subscriber configuration
Default Behavior	no (max-num = 0), which will say subscriber cannot use DHCP to obtain an IP address

This command configures a maximum number of IP addresses this subscriber can request via the DHCP protocol. A DHCP max-addrs>0 may be configured in the subscriber profile to allow this subscriber to use the DHCP protocol to get a dynamic IP address. The maximum address size may be configured between 1 and 255, according to one embodiment.

Command	[no] debug dhcp-relay packet [no] debug dhcp {all | mac = hh:hh:hh:hh:hh:hh | packet |relay
Command Mode	Exec(10)

These commands may be used for debugging purposes.

Command	show dhcp relay server
Command Mode	Exec(10)

This command displays information regarding the configured DHCP server.

Command	show dhcp relay hosts
Command Mode	Exec(10)

This command displays all the IP-hosts learnt by the relay/proxy functionality and the known information such as lease time.

Command	show dhcp relay shmem
Command Mode	Exec(10)

This command displays all the IP-hosts learnt by the relay/proxy functionality and written to the file/microdrive.

According to one embodiment, the DHCP server states are preserved within a network element, which may be used by the relay and/or proxy functionality of the network element. FIG. **6** is a state diagram illustrating an exemplary information flow within a network element according to one embodiment of the invention. In one embodiment, referring to FIG. **6**, an interface state manager (ISM) **601** on the XCRP is running in a "hot" mode between a primary and a secondary XCRP, and ISM **601** is the main responsible for state replication. Meanwhile, DHCP demon **602** writes DHCP state to the micro-drive for every DHCP IP address entry, such as, for example, IP address, MAC address, create time, lease time, circuit information (e.g., slot, port, VPI, and VCI, etc.), which may be stored in a data structure, such as data structure **500** shown in FIG. **5**, also referred to as a DHCP preserve state file.

In one embodiment, DHCP state preservation information may be used in at least one of the following situations:

Process Restart	DHCP preserve state file on micro-drive is read, but ISM information has higher priority
Power Cycle	DHCP preserve state file is read and has priority over ISM information
XCRP Switchover	DHCP preserve state is created from the "hot" running ISM module on the secondary XCRP, and from this information is the preserve state file written to the new micro-drive

According to one embodiment, DHCP demon **602** removes a dynamic DHCP IP address from a circuit in at least one following situations and sends an RADIUS accounting stop record:

Network Element Event	DHCP Relay	DHCP Proxy
Circuit delete	Yes	Yes
IP address given to another circuit	Yes	Yes
DHCP lease time expired	No	Yes

FIG. **7A** is a block diagram illustrating an exemplary network configuration according to one embodiment of the invention. In this embodiment, each context is deployed with individual DHCP servers. An exemplary configuration program associated with the network configuration of FIG. **7A** is shown in FIG. **8A**.

FIG. **7B** is a block diagram illustrating an exemplary network configuration according to one embodiment of the invention. In this embodiment, a global DHCP server, which will service multiple contexts and using intercontext routing to reach the global DHCP server from the individual service contexts. An exemplary configuration program associated with the network configuration of FIG. **7B** is shown in FIG. **8B**.

As described above, when a network element's DHCP proxy functionality is activated, all clients connected to the network element would consider the network element as a DHCP server. As a result, multiple DHCP servers may be implemented behind the network element without the knowledge of the clients. FIG. **9** is a block diagram illustrating an exemplary network configuration according to one embodiment of the invention. Referring to FIG. **9**, in one embodiment, network element **901** includes, but not limited to, an interface IF**1** serving as a DHCP proxy on behalf of multiple DHCP servers **903**-**905**. However, client **902** only considers network element **901** as the DHCP server. According to one embodiment, DHCP **904** may serve as a redundant DHCP server for DHCP **903**. When DHCP **903** is not operating, DHCP **904** may take over on behalf of DHCP **903**.

In one embodiment, network element maintains information regarding which interface or client is serviced by which DHCP server. In addition, multiple DHCP servers may share the same IP address pool, such that when the primary DHCP is down, the secondary DHCP may take over using the same IP address pool without causing conflicts. For example, DHCP **903** and DHCP **904** may be configured as a redundant DHCP server pair and they may share the same IP address pool. When DHCP **903** is down, DHCP **904** may take over immediately since DHCP **904** knows the IP address allocation performed by DHCP **903**.

Furthermore, according to one embodiment, network element **901** may monitor the activities of all DHCP servers on a per client basis for renewal or release. In a particular embodiment, network element **901** may maintain DHCP servers on a per interface basis, such as, per GI address basis.

According to one embodiment, a network element having DHCP redundant functionality described above may be configured via at least one of the following commands:

Command	[no] dhcp relay server ip-addr [giaddr ip-addr]
Command Mode	Context configuration
Default Behavior	no dhcp relay server is configured, but if a DHCP server is configured, then by default the primary IP-address of the interface is used as the giaddr

This command enables DHCP relay and proxy functionality in this context. All DHCP requests received on interfaces in this context will be forwarded to an external DHCP server with IP-address x.x.x.x. This command may be used multiple times to configure up to a predetermined number (e.g., five) of DHCP servers per context. The giaddr option is used to specify what IP-address to use in the DHCP packets' giaddr field.

Command	[no] dhcp timeout timeout
Command Mode	Context configuration
Default Behavior	Timeout interval is 10 seconds

This command sets the maximum time the network element is to wait for a response from a DHCP server before assuming that a packet is lost, or that the DHCP server is unreachable.

Command	[no] dhcp algorithm {first | round-robin}
Command Mode	Context configuration
Default Behavior	The network element queries the first configured server first

This command configures the algorithm to be used among multiple DHCP servers.

Command	[no] dhcp deadtime interval
Command Mode	Context configuration
Default Behavior	The network element considers a non-response DHCP server for dead in 5 minutes

This command configures the time the network element will consider a non-responsive DHCP server as dead, and will not revert to and try the DHCP server again until the timeout has expired (unless all other DHCP servers are also non-responsive).

Since the DHCP server implementation often is centralized in a network element as well as Wi-Fi networks, it can be a considerable traffic overhead as well as place a big burden on the DHCP servers if DHCP lease timers are configured in the minutes for a large amount of subscribers. For example, referring to FIG. **2**, clients **203** communicate with DHCP servers **202** directly via a DHCP relay interface of network element **201** for renewal and release of IP addresses. If clients **203** include thousands of clients and each of those clients has an IP address having a relatively short time leased from DHCP **202**, the overhead traffic incurred on DHCP **202** would be significantly large. In addition, since network element **201** is involved in a relay mode, network element **201** has no knowledge whether an IP address has been released since the respective client directly releases the IP address back to DHCP **202** without involving network element **201**. As a result, network element **201** keeps listening the traffic associated with that IP address even though it may be already released. Furthermore, when another client requests for an IP address, that released IP address cannot be assigned by network element **201** because network element **201** may still think that IP address has not been released yet.

However, if network element **201** maintains the lease time of IP addresses for its clients, the renewal and release of the IP addresses may be handled by network element **201** without invoking DHCP **202**. For example, according to one embodiment, when client **204** initially requests for an IP address, thinking that network element **201** is the DHCP server, network element **201** requests an IP address from DHCP **202** on behalf of client **204** with relatively large block of lease time, which may be larger than the one requested by client **204**. When network element **201** forwards the allocated IP address to client **204**, network element **201** allocates the requested lease time from the relatively large block of lease time allocated from DHCP **202** and assigned to client **204**.

Subsequently, according to one embodiment, when client **204** requests a renewal of the IP address, network element **201** checks the remaining relatively large block of lease time corresponding to the IP address of client **204** to determine whether the remaining lease time of the block is grater than or equal to the requested lease time for renewal, if so, network element **201** allocates again from the larger block of lease time maintained by the network element to the client without involving DHCP **202**. These renewal processes do not involve DHCP **202** until some threshold amount of lease time remains in the block of lease time (e.g.,) there is not enough lease time remaining in the block of lease time, in which case, network element **201** may request for another relatively large block of time from DHCP **202**. As a result, the overhead traffic incurred on DHCP **202** has been greatly reduced.

In addition, when client **204** releases the IP address, network element **201** knows when the IP address has been released and it may in turn release the IP address back to DHCP **202** and stop listening to the traffic associated with the released IP address.

FIG. **10** is a flow diagram illustrating an exemplary process for DHCP discovery according to one embodiment of the invention. Referring to FIG. **10**, according to one embodiment, when network element **1001** receives a DHCP discovery request from client or subscriber **1002**, network element **1001** authenticates client **1002** for a valid connection via RADIUS **1003**. The subscriber record with subscriber specific options and parameters, including, for example, the "idle timer" is read either from RADIUS **1003** or from a local subscriber database. In a CLIPS case, the MAC address of the subscriber may be used as the subscriber's ID. In a "bind subscriber" case, the subscriber name is known from the binding processes. When subscriber **102** is authenticated, the DHCP discovery packet is forwarded to DHCP server **1004** in the context where the subscriber is terminated. In response, a DHCP offer is received at network element **1001** from DHCP **1004**, including, but not limited to, DHCP options, such as the lease time. In one embodiment, the lease time in the DHCP offer received from DHCP **1004** is relatively larger than the lease time requested by client **1002**.

According to one embodiment, network element **1001** changes the DHCP options, such as the lease time to reflect the subscriber **1002** specification configuration (e.g., lowest value of the subscriber idle timer and the DHCP server applied lease time. Network element **1001** may also store the DHCP server **1004**'s lease time in the subscriber record maintained by the network element for future use. Thereafter the DHCP offer packet is forwarded to subscriber **1002**. Subsequently, when subscriber **1002** sends a DHCP request to network element **1001**, thinking that the network element is the DHCP server, network element **1001** forwards the DHCP request packet to DHCP **1004** and receives a DHCP reply packet from the DHCP **1004**. Network element **1001** modifies the DHCP options again to reflect the same values as in the offer packet, before sending it to subscriber **1002**.

According to one embodiment, network element **1001** maintains two "lease times" for subscriber **1002**. One is the lease time received from DHCP **1004**, which is needed for the network element to know when a DHCP renewal requires to be forwarded to DHCP **1004**. The other one is the actual lease time of subscriber **1002**, which indicates when it is safe for the network element to give a local response to the subscriber renewal request without invoking the DHCP server. Other operations may be included.

FIG. **11** is a flow diagram illustrating an exemplary DHCP renewal process according to one embodiment of the invention. Referring to FIG. **11**, according to one embodiment, when network element **1101** receives a DHCP lease renewal request from subscriber **1102**, network element **1101** checks the subscriber session time since the last DHCP lease time value was received from the DHCP server. Network element **1101** may use the T1 timer from DHCP **1104** to determine how to react to the subscriber's renewal request.

In one embodiment, if the subscriber session time is less than DHCP T1 timer (e.g., there is more time left in the lease time allocated from DHCP **1104**, where T1=x*duration of lease time), the network element may immediately send a DHCP reply packet to acknowledge the lease renewal for the subscriber without invoking DHCP **1104**.

If the subscriber session time is greater or equal to the DHCP T1 timer (e.g., no enough lease time left in the lease time previously allocated from DHCP **1104**), network element **1101** may forward the DHCP lease renewal packet to DHCP **1104** for more lease time. In response, network element **1101** receives a DHCP reply from DHCP **1104** including, but not limited to, DHCP options such as the lease time, which may include a longer lease time longer than the one requested by client **1102**. When network element **1101** forwards the packet client **1102**, the DHCP lease time is changed to reflect the subscriber specific configuration (e.g., the lowest value of the subscriber idle timer and the DHCP server applied lease time). Meanwhile, network element **1101** may also update the subscriber record regarding the lease time from DHCP **1104** for future use. Thereafter, network element **1101** forwards the DHCP acknowledge packet back to subscriber **1102**. Other operations may be included.

In the foregoing specification, the invention has been described with reference to specific exemplary embodiments thereof. It will be evident that various modifications may be made thereto without departing from the broader spirit and scope of the invention as set forth in the following claims. The specification and drawings are, accordingly, to be regarded in an illustrative sense rather than a restrictive sense.

What is claimed is:

1. A method in a network element, wherein the network element is coupled with a client and a set of one or more Dynamic Host Configuration Protocol (DHCP) servers, the method comprising the steps:

receiving, at the network element from the client, a DHCP discover packet;

modifying the DHCP discover packet by replacing a source IP address of the DHCP discover packet with a first IP address of the network element;

transmitting, to the set of one or more DHCP servers, the modified DHCP discover packet;

receiving, at the network element, a DHCP offer packet from at least one of the set of DHCP servers;

modifying the DHCP offer packet by replacing a source IP address of the DHCP offer packet with a second IP address of the network element;

transmitting the modified DHCP offer packet to the client;

receiving, at the network element from the client, a DHCP request packet;

modifying the DHCP request packet by replacing a source IP address of the DHCP request packet with the first IP address of the network element;

transmitting, to at least one of the set of DHCP servers, the modified DHCP request packet;

receiving, at the network element, a DHCP acknowledgement packet from the one of the set of DHCP servers;

modifying the DHCP acknowledgement packet by replacing a source IP address of the DHCP acknowledgement packet with the second IP address of the network element; and

transmitting the modified DHCP acknowledgement packet to the client.

2. The method of claim **1**, wherein the first IP address and the second IP address of the network element are different.

3. The method of claim **1**, wherein the set of DHCP servers include an active DHCP server and a redundant DHCP server configured in a pair, and wherein the redundant DHCP server takes over the services of the active DHCP server when the active DHCP server is down.

4. The method of claim **3**, wherein the active and redundant DHCP servers share the same IP address pool to provide IP addresses to clients.

5. The method of claim **1**, further comprising:

wherein the DHCP offer packet received from the at least one of the set of DHCP servers indicates a lease of an IP address for a first amount of lease time; and

prior to transmitting the modified DHCP offer packet to the client, further modifying the DHCP offer packet by indicating a lease of an IP address for a second amount of lease time, wherein the second amount of lease time is smaller than the first amount of lease time.

6. The method of claim **5**, further comprising:

receiving, from the client, a DHCP renewal request;

determining that the time remaining on the first amount of lease time is greater than or equal to an amount of time of a requested lease time renewal; and

transmitting a reply to the client acknowledging the renewal without involving the set of DHCP servers.

7. The method of claim **1**, further comprising installing a host route and an Address Resolution Protocol (ARP) entry for the client.

8. The method of claim **1**, further comprising:

receiving, from the client, a release request;

modifying the release request by replacing a source IP address of the DHCP offer packet with the first IP address of the network element; and

transmitting the modified release request to the one of the set of DHCP servers that assigned an IP address to the client.

9. A network element, comprising:

a processor; and

a memory coupled to the processor having instructions that, when executed by the processor, cause the processor to perform operations including,

receive, at the network element from a client, a DHCP discover packet;

modify the DHCP discover packet received from the client by replacing a source IP address of the DHCP discover packet with a first IP address of the network element;

transmit, to a set of one or more DHCP servers, the modified DHCP discover packet;

receive, at the network element, a DHCP offer packet from at least one of the set of DHCP servers;

modify the DHCP offer packet by replacing a source IP address of the DHCP offer packet with a second IP address of the network element;

transmit the modified DHCP offer packet to the client;

receive, at the network element from the client, a DHCP request packet;

modify the DHCP request packet by replacing a source IP address of the DHCP request packet with the first IP address of the network element

transmit, to at least one of the set of DHCP servers, the modified DHCP request packet;

receive, at the network element, a DHCP acknowledgement packet from the one of the set of DHCP servers;

modify the DHCP acknowledgement packet by replacing a source IP address of the DHCP acknowledgement packet with the second IP address of the network element; and

transmit the modified DHCP acknowledgement packet to the client.

10. The network element of claim **9**, wherein the first IP address and the second IP address of the network element are different.

11. The network element of claim **9**, wherein the set of DHCP servers include an active DHCP server and a redundant DHCP server configured in a pair, and wherein the redundant DHCP server is configured to take over the services of the active DHCP server when the active DHCP server is down.

12. The network element of claim **11** wherein the active and redundant DHCP servers share the same IP address pool to provide IP addresses to clients.

13. The network element of claim **9**, wherein the memory further has instructions that, when executed by the processor, cause the processor to perform the following:

wherein the DHCP offer packet received from the at least one of the set of DHCP servers indicates a lease of an IP address for a first amount of lease time; and

prior to transmission of the modified DHCP offer packet to the client, further modify the DHCP offer packet by indicating a lease of an IP address for a second amount of lease time, wherein the second amount of lease time is smaller than the first amount of lease time.

14. The network element of claim **13**, wherein the memory further has instructions that, when executed by the processor, cause the processor to perform the following:

receive, from the client, a DHCP renewal request;

determine that the time remaining on the first amount of lease time is greater than or equal to an amount of time of a requested lease time renewal; and

transmit a reply to the client acknowledging the renewal without involving the set of DHCP servers.

15. The network element of claim **9**, wherein the memory further has instructions that, when executed by the processor, cause the processor to install a host route and an Address Resolution Protocol (ARP) entry for the client.

16. The network element of claim **9**, wherein the memory further has instructions that, when executed by the processor, cause the processor to perform the following:

receive, from the client, a release request;

modify the release request by replacing a source IP address of the DHCP offer packet with the first IP address of the network element; and

transmit the modified release request to the one of the set of DHCP servers that assigned an IP address to the client.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,143,479 B2
APPLICATION NO. : 13/557128
DATED : September 22, 2015
INVENTOR(S) : Arberg et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification

In Column 1, Line 8, delete "2004, which" and insert -- 2004, now Pat. No. 8,230,067, which --, therefor.

In Column 2, Line 20, delete "element 103" and insert -- element 101 --, therefor.

In Column 11, Line 60, delete "grater" and insert -- greater --, therefor.

In Column 12, Line 21, delete "subscriber 102" and insert -- subscriber 1002 --, therefor.

Signed and Sealed this
Twenty-first Day of June, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office